FIRE DETECTION USING NEAR-IR RADIATION AND SOURCE TEMPERATURE DISCRIMINATION

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Introduction

New fire detection concepts and algorithms are justified only if they improve upon existing ones with lower false alarm rates and greater sensitivity to starting fires. In addition, the detectors and signal processing instruments should be easy to operate and maintain, have high flexibility and be relatively inexpensive (Luck, 1991). Currently residential fire detectors include optical smoke sensors, ionization smoke sensors and temperature sensors (Grosshandler, 1992). Conventional smoke sensors utilize light scattering or smoke ionization measurements, while temperature sensors utilize thermocouple measurements. The disadvantages with conventional single sensor detectors are that there is a significant time delay between the start of the fire, and the transport of either combustion products or smoke to positions close enough to enable detection and single sensor detectors involve a high rate of false alarms due to changes in the operating environment. Combinations of smoke sensors and odor sensors which involve multiple fire signatures are less prone to false alarms (Okayama et al., 1994), but involve greater initial and maintenance costs.

More recently, there has been increased interest in the use of radiation emission sensors for fire detection since they have a fast response time and most natural fires are easily distinguished by the unsteady nature of the emitted radiation (Middleton, 1989, Grosshandler, 1992). The two most distinguishing features of a natural fire, particularly a luminous one, are its apparent source temperature and the power spectral density of the radiation intensities emitted from it. The objective of the present work was to investigate whether these two characteristics of natural fires could be exploited in a near-infrared fire detector operating on the principle of source temperature discrimination.

Experimental methods

The principle of operation of the near-infrared fire detector is similar to the two-wavelength optical pyrometer used for determining soot volume fractions and temperatures in laboratory scale fires (Sivathanu et al., 1991). For fire detection, the existence of high temperatures in the vicinity of the detector is sufficient to indicate the presence of a fire. Therefore, the spectral emissivity of any radiation source can be assumed to vary inversely with wavelength irrespective of its chemical composition. Using this assumption, the apparent temperature of any source can be determined from the measured spectral radiation intensities (I_λ) at two wavelengths (900 and 1000 nm) as:

$$T = \frac{hc}{k}\left(\frac{1}{\lambda_1} - \frac{1}{\lambda_2}\right) / \ln\left\{\left(\frac{\lambda_2^6}{\lambda_1^6}\right)\left(\frac{I_{\lambda 1}}{I_{\lambda 2}}\right)\right\} \qquad (2)$$

where h is the Planck's constant, k is the Boltzmann constant, and c is the speed of light. The advantage of using two wavelengths close to one other is that the assumption of $1/\lambda$ dependence for the emissivity of the source does not seriously affect the apparent source temperature obtained using Eq. (1). From the time series of spectral radiation intensities, measured at 900 and 1000 nm, a time series of apparent source temperatures is obtained using Eq. (1). This time series is statistically analyzed to determine an efficient method of distinguishing fires from background radiation such as sunlight, fluorescent and incandescent lamps. The apparent source temperatures obtained from measurements of the spectral radiation intensities emanating from four of six standard test fires specified in the European Committee for Standardization guidelines (CEN, 1982) were investigated during the present study.

Results and Discussion

The four test fires chosen for the present study were an heptane pool, a polyurethane plastic, a wooden crib and a smoldering cotton fire (CEN, 1982). The spectral radiation intensities at 900 nm and 1000 nm incident on the fire detector were measured with a sampling frequency of 500 Hz. The measurements were analyzed to obtain the probability density function (PDF) and power spectral density (PSD) of apparent source temperatures. The PDFs of spectral radiation intensities emanating from the test fires vary by more than two orders of magnitude. This implies that a detection algorithm based on the absolute magnitudes of the radiation intensities should have a very large dynamic range to detect fires with a wide variety of fuel composition. In addition, it has to be insensitive to the varying levels of background radiation from different sources such as the sun, incandescent lights, etc. This conflicting requirement is the major cause of false alarms in single channel radiation detectors.

The current detector is based on a statistical analysis of the apparent source temperatures. The PDFs of apparent source temperatures for the four flames are shown in Fig. 1. The apparent source temperatures are always biased towards the highest values present in the flame due to the strong non-linearity in the Planck function. The heptane, wood and plastic fires have fluctuating apparent source temperatures between 1500 K and 2000 K, while that of the smoldering cotton fire varies within a narrow range of 1000 K to 1100 K. Despite the two orders of magnitude differences in the spectral radiation intensities, all the four fires fall within a narrow range of apparent source temperatures. The Power Spectral Densities (PSDs) of apparent source temperatures obtained for the four test fires are shown in Fig. 2. The heptane pool, wooden crib and open plastic fires have most of the energy of the source temperature fluctuations concentrated at frequencies below 8 Hz. The PSDs for frequencies greater than 8 Hz show a rapid decline to the noise level (which is two orders of magnitude lower) and remains constant beyond 30 Hz. The PSD of the apparent source temperature fluctuations obtained from the cotton smoldering fire shows very similar characteristics, but at an order of magnitude lower frequencies. Based on these observations, a fire can be presumed to be present in the vicinity of the detector if and only if: (1) at least 60% of the apparent source temperatures is within 1000 to 2500 K, and (2) at least 40% of the energy of the apparent source temperature fluctuations is between 0.1 Hz and 40 Hz. The first condition is important to detect sources of high temperatures in the immediate vicinity of the fire detector. The second condition is important to eliminate ambiguous signals originating from natural and artificial sources such as incandescent and fluorescent lamps, solar radiation reflected from building materials, natural gas burners and electric hot plates. These two conditions can thus uniquely determine the presence of a fire.

Conclusions

A new type of fire detector which operates on the principle of apparent source temperatures obtained from spectral radiation intensity measurements at two near infrared wavelengths is demonstrated. The near-infrared fire detector is capable of detecting fires from a wide variety of materials with significantly lower false alarm rates and much higher response time than conventional detectors.

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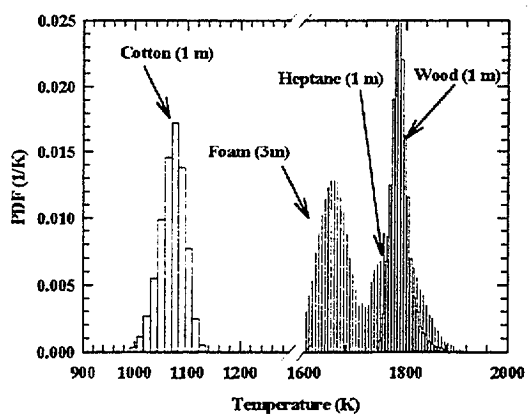

Figure 1. PDFs of apparent source temperatures.

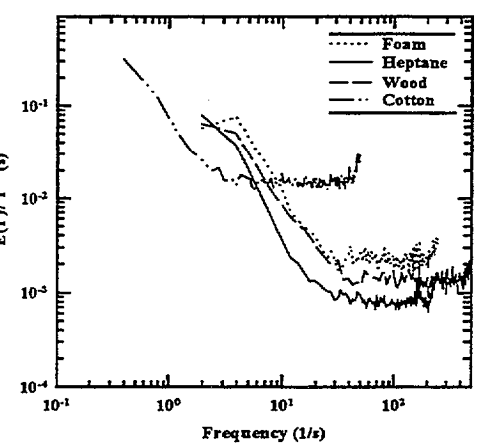

Figure 2. PSDs of apparent source temperatures.